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Comparison of the climate indices based on the relationship between yield loss of rain-fed winter wheat and changes of climate indices using GEE model

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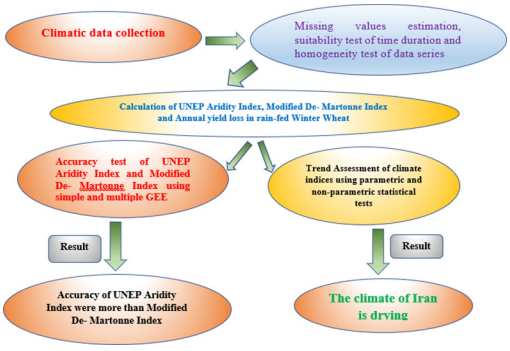
HIGHLIGHTS

- Using simple and multiple GEE to statistical analysis in this research is new.
- Trend of climate changes showed that Iran is drying.
- Correlation between AYL and climate indices was evaluated.
- The accuracy of the UNEP aridity index was more than MDM index.
- Results of this paper can be used to select climate index with more accuracy.

GRAPHICAL ABSTRACT


Climatic data collection
Missing values estimation, suitability test of time duration and homogeneity test of data series
Calculation of UNEP Aridity Index, Modified De- Martonne Index and Annual yield loss in rain-fed Winter Wheat
Accuracy test of UNEP Aridity Index and Modified De- Martonne Index using simple and multiple GEE
Trend Assessment of climate indices using parametric and non-parametric statistical tests
Result
Result
Accuracy of UNEP Aridity Index were more than Modified De- Martonne Index
The climate of Iran is drying

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ABSTRACT

Climate change is one of the most important meteorological phenomena that has had a lot of impacts on different sections with different spatial scales. In recent decades, climate changes affected by various factors especially human activities have had various impacts in different sections such as melting glaciers, various flood occurrence, occurrence of different droughts and etc. UNEP aridity Index (UNEP) and Modified De-Martonne index (MDM) are two more used indices to evaluate climate conditions in various regions of the world. In this paper; 1) the temporal trend of changes in climate conditions based on UNEP and MDM indices using climatological data (from 1967 to 2017) of 16 meteorological stations using parametric and non-parametric statistical tests were evaluated 2) the accuracy of UNEP and MDM indices were compared to assess climate conditions, based on the correlation between mentioned indices and percent of annual yield loss (AYL) in rain-fed winter wheat using simple and multiple Generalizes Estimation Equation (GEE) methods (for help managers to select more suitable and more accurate index to assess climate condition). Results showed, based on UNEP and MDM indices, climate indices in 93.75% and 87.5% of stations had a decreasing trend, but decreasing trend only in 56.25% and 50% of stations were significant at 5% level (respectively). The evaluation of the accuracy of UNEP and MDM indices showed that, in all stations, $|B|$ coefficients between calculated AYL and UNEP and MDM indices and R^2 coefficients between simulated AYL using AquaCrop model and predicted AYL using simple and multiple GEE methods in UNEP aridity index were more than MDM index. So, it is recommended to use UNEP aridity index to assess the climate conditions in different regions.

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1. Introduction

Climate is the average of the weather conditions of each region in long-term (Hore et al., 2018; Kenyon, 2018; Richardson et al., 2018). In recent decades, different parameters such as human activities, increasing greenhouse gases, deforestation, industrialization, increase in carbon dioxide production and etc. have caused climate changes in different regions (Fang et al., 2018; Pau et al., 2018; Tang et al., 2018). Climate changes in different parts of the world has caused a lot of problems such as desertification, land degradation, melting glaciers, reduce biodiversity, various flood occurrence, impact on human health, occurrence of various droughts, economic impacts, migration and etc. (Zareiee, 2014; Abel et al., 2018; Bryndum-Buchholz et al., 2018; Markus et al., 2018; Silva and Costa, 2018; Tol, 2018), therefore, assessment of the climatic conditions in different regions of the world is very important to manage and reduce the negative impacts of this phenomena. UNEP aridity index (UNEP) and Modified De-Martonne index (MDM) are two more used indices to evaluate climate conditions in various regions of the world (De-Martonne, 1926; UNEP, 1992; Aguirre et al., 2018; Zarei, 2018).

Wen et al. (2018) used UNEP index to evaluate spatiotemporal variation of climate in Loess Plateau of China. They used meteorological data of 51 stations from 1961 to 2014. Results of this research showed the annual aridity index in the study area had a downward trend and the area of dryland regions was expanded. Şarlak and Agha (2018) assessed spatial and temporal variations of aridity in Iraq using UNEP and MDM indices. Nouri and Bannayan (2018) evaluated spatiotemporal changes in aridity index over semi-arid and humid regions of Iran using climatic data series of 22 stations from 1966 to 2012. Results of this paper indicated a decreasing trend in aridity index in 3-month and 12-month time scales. Cheval et al. (2017) used UNEP, MDM and 3 other indices to evaluate the variability of the aridity in South-Eastern Europe. Results indicated that South-Eastern Europe is warming and the general aridity spatial pattern remains steady along 1961–2050.

Masoudi et al. (2018) used MDM index to evaluate the trend of climate changes in Southern Khorasan Province, Iran. They used climatic data series of 10 stations from 1989 to 2012. According to the results, about 76% of the extent of the study area has become drier. Milentijević et al. (2018) assessed aridity of Leskovac basin in Serbia using De-Martonne index and 3 other indices. Mianabadi et al. (2018) used De-Martonne and Budyko indices to assess trends of major climatic variables in Iran. Amirnejad and Asadpour (2017) evaluated the effects of climate changes on wheat production in Iran. Results of this paper indicated that climate changes in short-term and long-term have a significant effect on wheat production. Bannayan et al. (2010) assessed the correlation between aridity index and yield of rain-fed wheat and barley in Khorasan province using data series from 1985 to 2005. Results of this paper showed a significant correlation between the aridity index and yield of rain-fed wheat and barley. Chowdhury (2018) evaluated the intensity and distribution of aridity over Bangladesh using De-Martonne index, UNEP aridity index and 5 other indices. In this study, the data series of 34 meteorological stations during 1991–2010 were used to assess the aridity distribution and variation. Many researchers used De-Martonne index or UNEP aridity index to evaluate climate conditions in different parts of the world such as: Barzani and Salleh, 2017; Araghi et al., 2018; Chen et al., 2018; Hájková et al., 2018; Jones, 2018; Moser et al., 2018; Nyamtseren et al., 2018; Stonevičus et al., 2018.

Due to the widespread use of the Modified De-Martonne index and UNEP aridity index to assess the climate conditions with researchers, so, the objectives of this paper are; 1) Assessment of the temporal changes trend in climate conditions in Iran using MDM and UNEP aridity indices based on parametric and non-parametric statistical tests. 2) Evaluation of the accuracy of UNEP and MDM indices to assess the climate conditions, based on the correlation between MDM and UNEP aridity indices and percent of annual yield loss (AYL) in winter wheat using simple and multiple Generalizes Estimation Equation (GEE) methods.

2. Material and methods

2.1. Study area

Iran is located in the south west of Asia. Geographical location of Iran has been extended from 25°05′ to 39°78′ Northern latitude and 44°08′ to 63°30′ Eastern longitudes, with an area about 168×10^6 Hectares (Fig. 1). Elevation of this area varies from −59 m from sea level at the Caspian coasts to >5300 m from sea level at the Damavand mountain. Climate conditions of Iran vary from hyper-humid in northern regions to hyper-arid in southeast parts of Iran, but in general arid and semi-arid climate conditions prevail climate of the region (Zarei et al., 2016; Zarei and Mahmoudi, 2017). The average of annual precipitation of Iran varies from <100 mm at the central and southeast parts to >2000 mm at the Caspian coasts. The average of monthly temperature of the study area varies from <10 (Celsius) at the northwest parts to >25 (Celsius) at the central and south regions of Iran. In this research climatic data series of 16 stations with adequate time duration (51 years) were used to calculate UNEP aridity index, MDM index and AYL (%). Some of the climatic characteristics and spatial positions of selected stations are presented in Table 1.

2.2. Methodology

2.2.1. Data collection

In this research to calculate UNEP Aridity Index, Modified De-Martonne index and annual yield loss (%), climatic data (include monthly precipitation, average of minimum monthly temperature, average of maximum monthly temperature, Average of monthly relative humidity, average of monthly wind speed, average of monthly sunshine and monthly evapotranspiration) of 16 synoptic stations (Ahvaz, Arak, Babolsar, Esfahan, Ghazvin, Gorgan, Kerman, Mashhad, Ramsar, Rasht, Sanandaj, Shiraz, Tabriz, Tehran, Zabol and Zanjan stations) during 1967–2017 were used. Mentioned required data was prepared from Iran Meteorological Organization (http://www.irimo.ir). Before using the data, missing values of data in all stations were estimated via Normal Ratio method; suitability of time duration in all stations was evaluated using Mockus method and the homogeneity of data series in all stations was assessed using double mass curve method (Mahdavi, 2002).

2.2.2. UNEP aridity index and Modified De-Martonne index

UNEP aridity index is one of the numerical indices to evaluate the climate conditions and developed by UNEP (1992). This index is based on the ratio of P and PET parameters and calculated using Eq. (1):

$$Ai = \frac{P_i}{PET} \tag{1}$$

where: Ai is aridity index, P_i is precipitation and PET is potential evapotranspiration (In this paper to estimate PET, FAO Penman-Monteith (FAO 56) method were used (Allen et al., 1998)). For more details about UNEP aridity index, it is suggested to see Hwang et al., 2018; Zarei, 2018.

Modified De-Martonne index developed by De-Martonne, 1926 is based on the ratio of precipitation and temperature parameters and calculated using Eq. (2):

$$I = \frac{P_i}{T + 10} \tag{2}$$

where: I is Modified De-Martonne index, P_i is Average of precipitation and T is average of temperature. For more details about Modified De-Martonne index, it is suggested to see Aguirre et al., 2018;

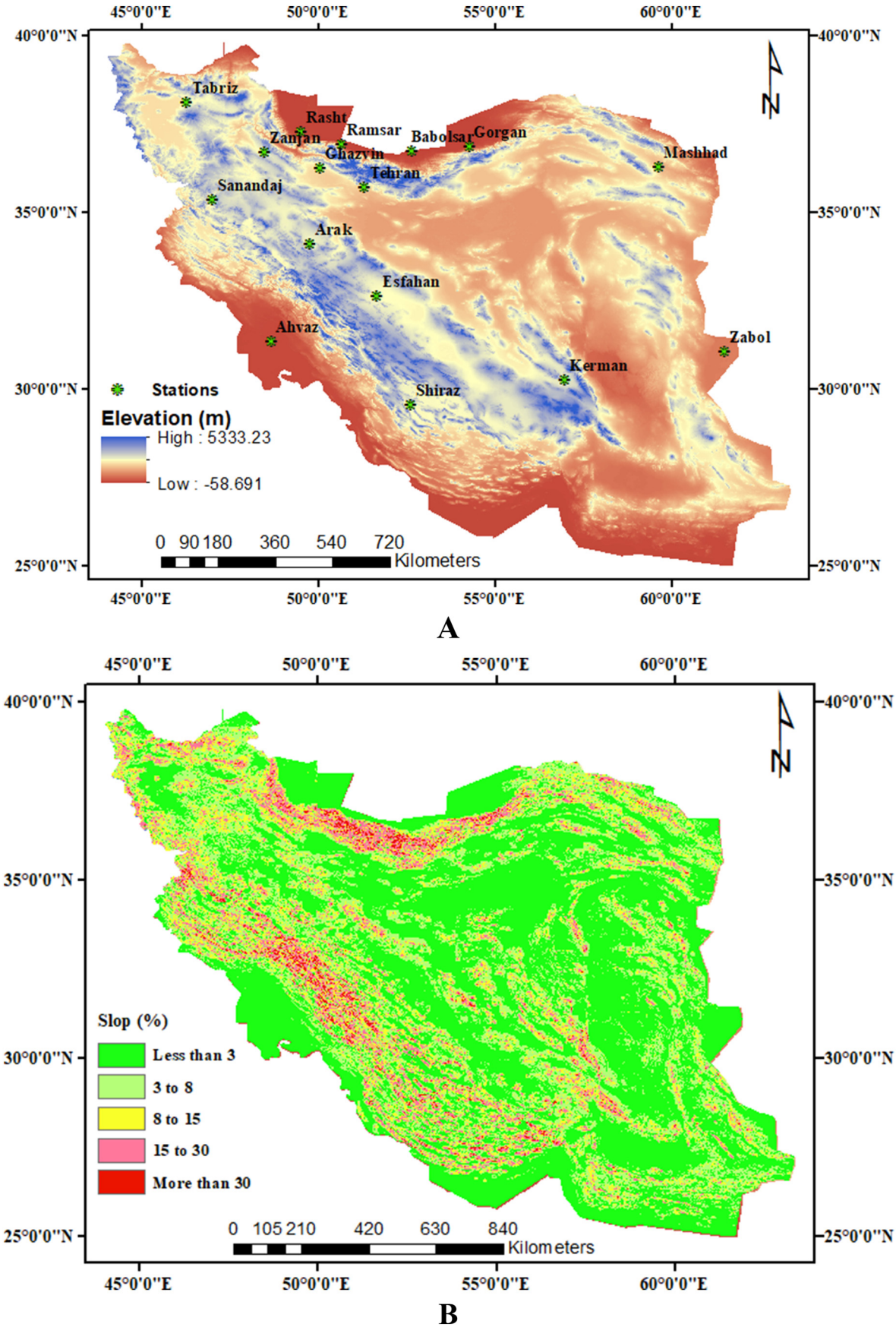

Fig. 1. Location of the Study area. A: Dem (digital elevation model) of study area and spatial distribution of synoptic stations and B: Slop map of the study area.

Table 1
Meteorological and geographical characteristics of synoptic stations.

Row	Stations name	Latitude (UTM)	Longitude (TUM)	Geographic zone number	Elevation (m a.s.l)	Average monthly precipitation (mm/year)	Average monthly temperature (C)	Annual climate index
1	Ahvaz	3468896	277996	39	21.89	19.12	25.71	6.428
2	Arak	3773930	386234	39	1707.78	26.90	13.93	13.484
3	Babolsar	4064710	647359	39	−21.18	76.32	17.30	33.584
4	Esfahan	3608988	562545	39	1549.79	10.66	16.53	4.820
5	Ghazvin	4012096	414648	39	1279.21	26.52	14.01	13.272
6	Gorgan	4081720	256295	40	12.84	47.26	17.73	20.464
7	Kerman	3346488	496793	40	1752.93	11.44	16.03	5.278
8	Mashhad	4016743	736559	40	999.32	21.30	14.74	10.346
9	Ramsar	4083831	470302	39	−19.84	101.71	16.10	46.727
10	Rasht	4123524	375839	39	−6.29	112.77	16.16	51.750
11	Sanandaj	3911844	681772	38	1372.76	36.62	13.74	18.526
12	Shiraz	3268144	655043	39	1484.28	26.79	18.11	11.449
13	Tabriz	4215838	612547	38	1360.21	22.70	12.83	11.946
14	Tehran	3948872	528654	39	1189.87	19.75	17.74	8.538
15	Zabol	3434283	355252	41	489.21	4.60	22.30	1.707
16	Zanjan	4062695	275130	39	1662.78	25.25	11.71	13.960

Note. *: Climate index was evaluated using Modified De-Martonne index.

Chowdhury, 2018; Mianabadi et al., 2018. Categories of climate conditions based on UNEP aridity index and Modified De-Martonne index are presented in Table 2.

2.2.3. Annual yield loss (%) calculation

In many investigations, crop models are used to assess the effects of climate changes on rain-fed crops yield. AquaCrop model is one of the most popular crop models that used to simulate crop growth due to its user-friendly structure, simplicity and low input data requirement. More details were described by Steduto et al. (2012) and Tigkas and Tsakiris (2015). Similar to other crop models, AquaCrop model should be calibrated and validated for each crop species. Shirshahi et al. (2018) calibrated and validated AquaCrop model for winter wheat (rain-fed winter wheat) based on data of two-year and 5-year field experiments, respectively. Their results showed that the AquaCrop model can accurately predict winter wheat yield. In this study, conservative and non-conservative parameters of AquaCrop model were changed based on presented values by Shirshahi et al. (2018) for winter wheat. In this study after tuning of AquaCrop model parameters, rain-fed and potential (no water stress) yields of winter wheat were predicted in all stations (16 stations) for 51 years. To assess the effect of climate changes, the percentage of annual yield loss was calculated as follows (Tigkas et al., 2018):

$$\%Y_{li} = \frac{Y_i - Y_{pi}}{Y_{pi}} \times 100 \quad (3)$$

where $\%Y_{li}$is the yield loss, $Y_i$and $Y_{pi}$are the rain-fed and potential winter wheat yield (Respectively).

Table 2
Climatic classification of Modified De-Martonne index and UNEP Aridity index (UNEP, 1992; Zarei and Mahmoudi, 2017; Zarei, 2018; De-Martonne, 1926; Aguirre et al., 2018).

UNEP aridity index (AI)			Modified De-Martonne index (I)		
Symbol	Climate condition	Range of AI	Symbol	Climate condition	Range of I
H	Humid	>0.65	HHB	Hyper humid type B	55<
SH	Sub-humid	0.5 to 0.65	HHA	Hyper humid type A	35 to 55
SA	Semi-arid	0.2 to ≤0.5	H	Humid	28 to 35
A	Arid	0.05 to ≤0.2	SH	Sub-humid	24 to 28
HA	Hyper arid	≤0.05	M	Mediterranean	20 to 24
			SA	Semi-arid	10 to 20
			A	Arid	5 to 10
			HA	Hyper-arid	≤5

2.2.4. Trend assessment of climate conditions and AYL

In this research to evaluate trend of changes in climate conditions and percent of annual yield loss in all stations, at the first stage, normality of calculated data series of climate indices based on UNEP aridity index and Modified De-Martonne index and data series of percent of annual yield loss in all stations using Kolmogorov-Smirnov test were assessed. Then, to evaluate the trend of changes in data series, in normal data series, Pearson test and in non-normal data series, Spearman Rho test were used. It is suggested to see Tabari et al. (2015); Da Silva et al. (2018); Pandey and Khare (2018) and Stevens-Rumann et al. (2018) for more details about Pearson and Spearman Rho tests.

2.2.5. Simple and multiple Generalizes Estimation Equation (GEE)

To investigate the relationship between a dependent response variable and a set of independent variables (predictors) when the observations are dependent, we faced with a repeated-measures panel data problem. There are different methods such as fixed and random effects models and Generalizes Estimation Equation (GEE) to solve this problem (Gardiner et al., 2009). GEE gives more robust estimators than other methods. Therefore, this method is suggested to apply in real problems (Hu et al., 1998; Ballinger, 2004; Ghisletta and Spini, 2004).

In this research, the variable Y was the response (dependent) variable (Simulated data series of annual yield loss (%) in rain-fed winter wheat using AquaCrop model in each station). Also, the variables A and B were predictors (calculated data series of climate indices in each station based on UNEP aridity index and Modified De-Martonne index). The privilege of GEE technique led us to use it in the present research, because the repeated measurements Y_t and Y_{t-1} were much correlated ($p > 0.05$). The general equations of multiple and simple GEE are respectively presented in

$$Y_t = \beta_0 + \beta_A A_t + \beta_B B_t + \epsilon_t, \quad (4)$$

$$Y_t = \beta_0 + \beta_A A_t + \epsilon_t, \quad (5)$$

$$Y_t = \beta_0 + \beta_B B_t + \epsilon_t, \quad (6)$$

where β_i's are model parameters (coefficients), ϵ_t is the random component of the model, that follows a random distribution with mean of 0 and A_t and B_t are independent parameters or predictors.

In this paper, A_t and B_t are calculated data series of climate indices in each station based on UNEP aridity index and Modified De-Martonne index.

In the GEE method, the parameters are estimated through an iterative procedure such as the estimated model will optimize the fitting

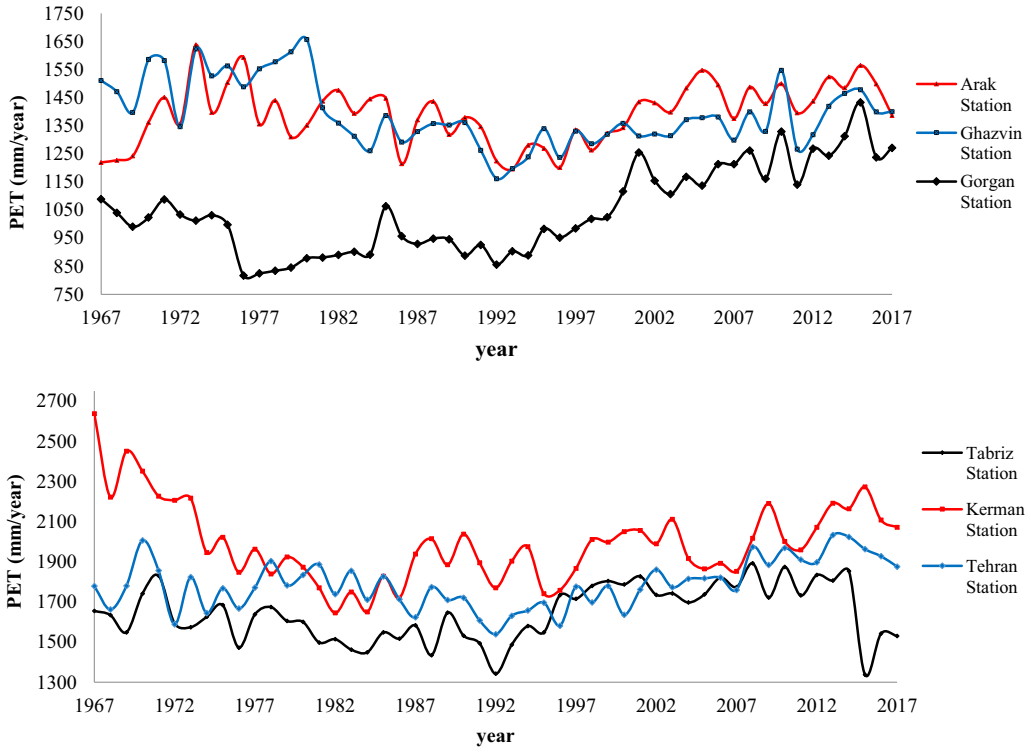

Fig. 2. Calculated Annual potential evapotranspiration (PET) in some of the selected stations (for example).

model to a dataset. To run GEE, we need a link function and a working correlation matrix that depends on the distribution of the dependent variable (Y_t) and the correlations between Y_t and Y_{t-1}. In this work, the non-transforming identity link function and the first-order autoregressive, AR (1), the working correlation matrix were applied.

2.2.6. Comparison of the accuracy of UNEP aridity index and Modified De-Martonne index

In this research, for comparison of the accuracy of UNEP aridity index and Modified De-Martonne index to monitor the climate conditions, from; 1) the Beta coefficients ($|B|$) of simple and multiple GEE method

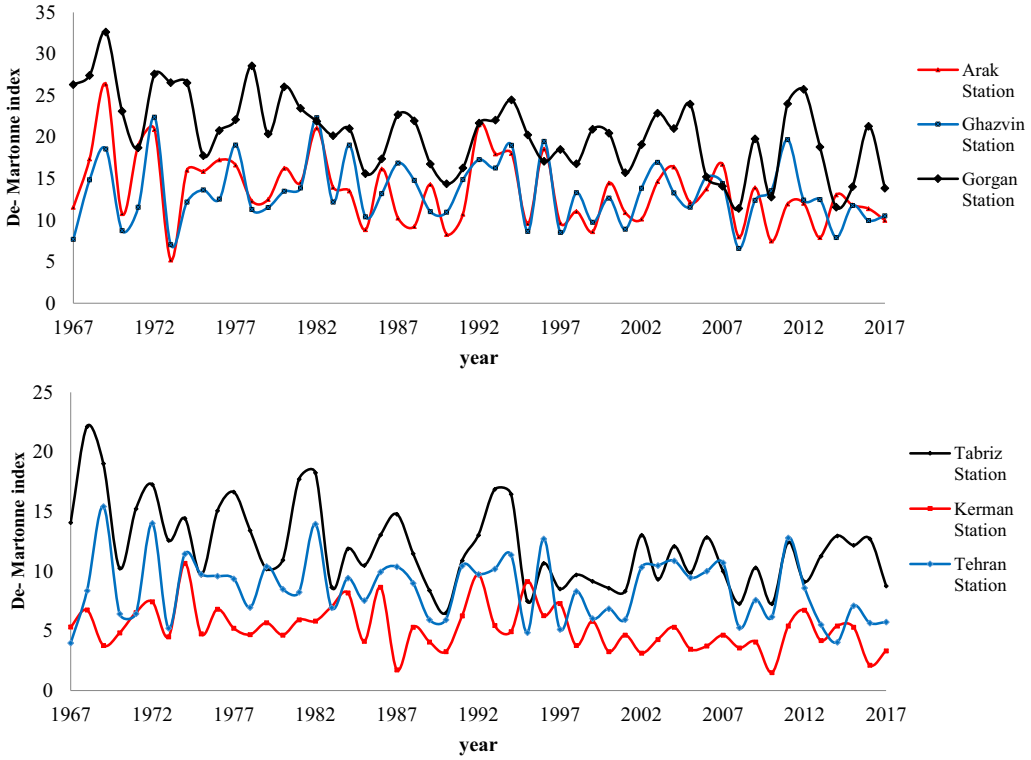

Fig. 3. Calculated Annual De-Martonne index in some of the selected stations (for example).

Table 3
Occurrence frequency (%) of different classes of climate conditions based on UNEP aridity index in short-term time scale (annual time scale) during 1967–2017 in selected stations.

Stations name	Climate classes				
	H	SH	SA	A	HA
Ahvaz	0.000	0.000	0.000	88.235	11.765
Arak	0.000	0.000	62.745	37.255	0.000
Babolsar	94.118	3.922	1.961	0.000	0.000
Esfahan	0.000	0.000	0.000	78.431	21.569
Ghazvin	0.000	0.000	56.863	43.137	0.000
Gorgan	33.333	27.451	39.216	0.000	0.000
Kerman	0.000	0.000	0.000	80.392	19.608
Mashhad	0.000	0.000	31.373	68.627	0.000
Ramsar	100	0.000	0.000	0.000	0.000
Rasht	100	0.000	0.000	0.000	0.000
Sanandaj	0.00	5.88	78.43	15.69	0.00
Shiraz	0.00	0.00	33.33	66.67	0.00
Tabriz	0.00	0.00	23.53	76.47	0.00
Tehran	0.00	0.00	7.84	92.16	0.00
Zabol	0.00	0.00	0.00	0.00	100
Zanjan	0.00	0.00	70.59	29.41	0.00

Note: H is humid class of climate condition, SH is sub-humid class of climate condition, SA is semi-arid class of climate condition, A is arid class of climate condition and HA is hyper-arid class of climate condition.

Table 4
Occurrence frequency (%) of different classes of climate conditions based on MDM index in short-term time scale (annual time scale) during 1967–2017 in selected stations.

Stations name	Climate classes							
	HHB	HHA	H	SH	M	SA	A	HA
Ahvaz	0.000	0.000	0.000	0.000	0.000	9.804	62.745	27.451
Arak	0.000	0.000	0.000	1.961	5.882	70.588	21.569	0.000
Babolsar	0.000	37.255	45.098	11.765	3.922	1.961	0.000	0.000
Esfahan	0.000	0.000	0.000	0.000	0.000	0.000	41.176	58.824
Ghazvin	0.000	0.000	0.000	0.000	3.922	76.471	19.608	0.000
Gorgan	0.000	0.000	3.922	17.647	37.255	41.176	0.000	0.000
Kerman	0.000	0.000	0.000	0.000	0.000	1.961	49.020	49.020
Mashhad	0.000	0.000	0.000	0.000	0.000	45.098	52.941	1.961
Ramsar	25.490	58.824	15.686	0.000	0.000	0.000	0.000	0.000
Rasht	35.294	60.784	3.922	0.000	0.000	0.000	0.000	0.000
Sanandaj	0.000	0.000	5.882	7.843	21.569	56.863	7.843	0.000
Shiraz	0.000	0.000	0.000	0.000	1.961	64.706	27.451	5.882
Tabriz	0.000	0.000	0.000	0.000	1.961	66.667	31.373	0.000
Tehran	0.000	0.000	0.000	0.000	0.000	31.373	62.745	5.882
Zabol	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.000
Zanjan	0.000	0.000	0.000	0.000	7.843	78.431	13.725	0.000

Note: HHB is hyper-humid Type B class of climate condition, HHA is hyper-humid Type A class of climate condition, H is humid class of climate condition, SH is sub-humid class of climate condition, M is Mediterranean A class of climate condition, SA is semi-arid class of climate condition, A is arid class of climate condition and HA is hyper-arid class of climate condition.

between data series of UNEP aridity index and Modified De-Martonne index (Independent parameters or predictor) and annual yield loss (%) of rain-fed winter wheat (dependent parameter) in each station and 2) R^2 coefficients between simulated annual yield loss (%) using AquaCrop model and predicted annual yield loss (%) using simple and multiple GEE methods were used. If |*B*| coefficient for one independent parameter were more than other parameters, so, the impact of that parameter in the GEE model to predict AYL is higher than other parameters. On the other hand, the greater the value of R^2 coefficients between simulated annual yield loss (%) using AquaCrop model and predicted annual yield loss (%) using simple and multiple GEE methods indicate the higher ability of GEE model to predict index AYL.

3. Results and discussion

3.1. Calculated PET

Results of calculated PET showed that, annual potential evapotranspiration (based on FAO 56 method) in stations with arid and semi-arid climate conditions such as Ahvaz, Zabol, Shiraz, Esfahan and Kerman stations that located at the south, southeast and southwest regions of study area was more than stations with semi-humid to hyper-humid climate conditions such as Ramsar, Rasht and Babolsar stations. According to the results, mean annual PET in Ahvaz, Arak, Babolsar, Esfahan,

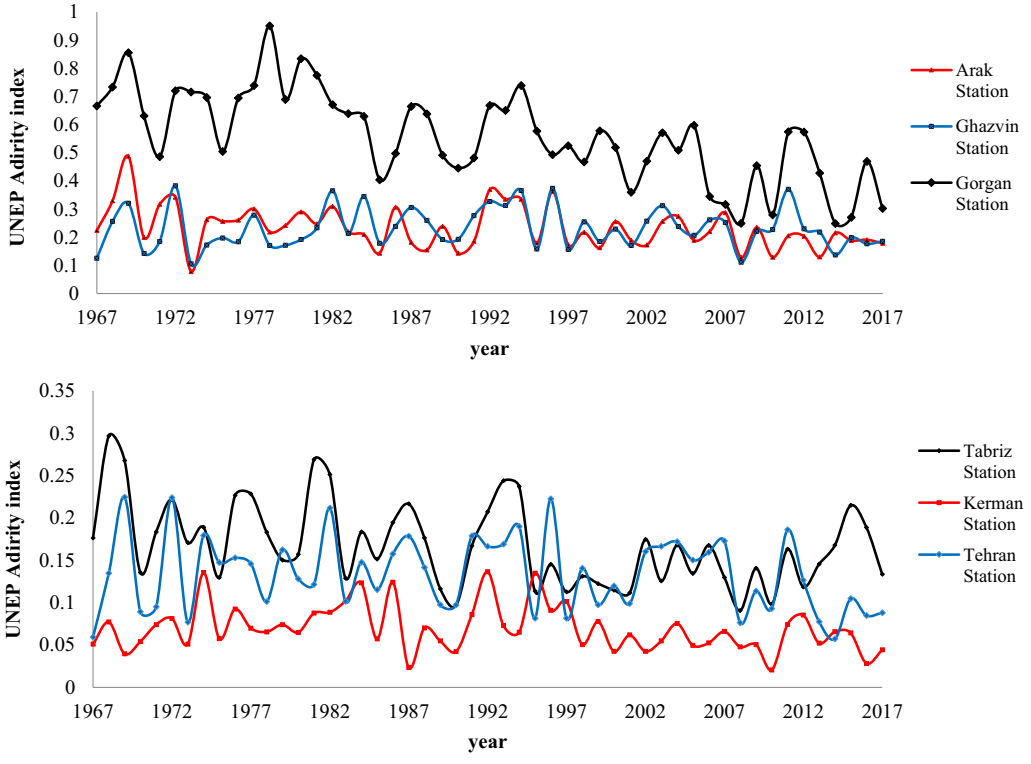

Fig. 4. Calculated Annual UNEP Aridity Index in some of the selected stations (for example).

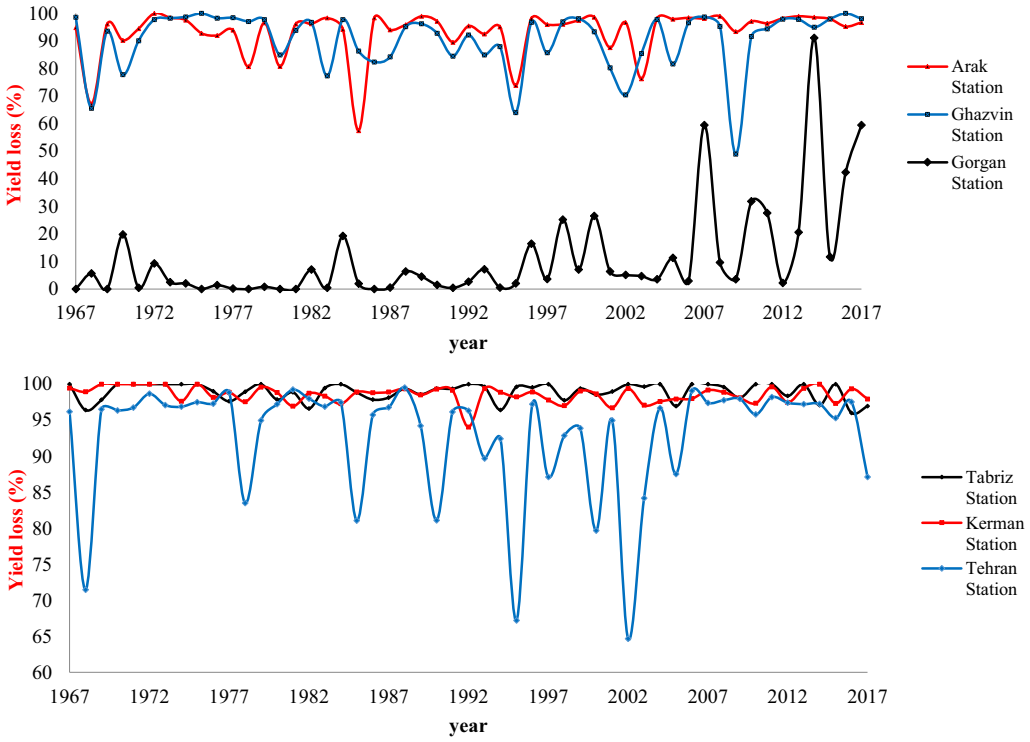

Fig. 5. Simulated AYL (%) using AquaCrop model in some of the selected stations (for example).

Ghazvin, Gorgan, Kerman, Mashhad, Ramsar, Rasht, Sanandaj, Shiraz, Tabriz, Tehran, Zabol and Zanjan stations were 2471.5, 1392.77, 938.27, 1603.19, 1393.34, 1046.25, 1993.21, 1470.15, 826.94, 852.97, 1452.60, 1781.94, 1642.72, 1785.86, 3167.96 and 1279.11 (mm/year), respectively. Calculated annual PET in some of the selected stations (for example) are presented in Fig. 2.

3.2. Calculated UNEP aridity index and Modified De-Martonne index

Calculated UNEP and MDM climate indices indicated that, based on UNEP aridity index, in long-term, the climate condition of Zabol station was hyper-arid, the climate condition of Ahvaz, Esfahan, Kerman, Mashhad, Shiraz, Tabriz and Tehran stations were arid, the climate conditions of Arak, Ghazvin, Sanandaj and Zanjan stations were semi-arid, the climate condition of Gorgan station was sub-humid and the climate condition of Babolsar, Ramsar and Rasht stations were humid. According to the results of UNEP index, in short-term, in stations with hyper-arid to semi-arid climate conditions, arid and semi-arid classes and in stations with sub-humid to humid climate conditions, humid and sub-humid classes of climate condition had the most Occurrence frequency (Fig. 3 and Table 3).

Based on MDM index in long-term, the climate condition of Zabol and Esfahan stations were hyper-arid, the climate condition of Ahvaz,

Table 5
Normality test of calculated data series of Modified De-Martonne index, UNEP Aridity index and simulated annual yield loss (%) using AquaCrop model in all stations using Kolmogorov-Smirnov test.

Stations name	Calculated data series of:		
	Modified De-Martonne index	UNEP Aridity index	Annual yield loss (%)
Ahvaz	0.723[a]	0.938[a]	0.124[a]
Arak	0.826[a]	0.686[a]	0.001
Babolsar	1.000[a]	1.000[a]	0.064[a]
Esfahan	0.886[a]	0.998[a]	0.333[a]
Ghazvin	0.531[a]	0.604[a]	0.039
Gorgan	0.984[a]	0.909[a]	0.001
Kerman	0.572[a]	0.546[a]	0.327[a]
Mashhad	0.196[a]	0.621[a]	0.041
Ramsar	0.299[a]	0.843[a]	0.000
Rasht	0.531[a]	0.735[a]	0.000
Sanandaj	0.915[a]	0.728[a]	0.049
Shiraz	0.977[a]	0.982[a]	0.211[a]
Tabriz	0.575[a]	0.723[a]	0.034
Tehran	0.759[a]	0.447[a]	0.000
Zabol	0.748[a]	0.418[a]	0.839[a]
Zanjan	0.998[a]	0.937[a]	0.012

[a] Data series is normal at the 0.05 significant levels.

Table 6
Calculated changes trend in data series of Modified De-Martonne index, UNEP Aridity index and simulated annual yield loss (%) using AquaCrop model in selected stations.

Stations name	Calculated data series of:		
	Modified De-Martonne index	UNEP Aridity index	Annual yield loss (%)
Ahvaz	−0.416[b]	−0.335[a]	0.199
Arak	−0.375[b]	−0.383[b]	**0.343**[a]
Babolsar	−0.141	−0.265	−0.002
Esfahan	0.020	0.062	0.333[a]
Ghazvin	−0.146	0.000	**0.011**
Gorgan	−0.561[b]	−0.713[b]	**0.630**[b]
Kerman	−0.355[a]	−0.254	0.067
Mashhad	−0.363[b]	−0.441[b]	**0.120**
Ramsar	−0.030	−0.160	**−0.122**
Rasht	−0.285[a]	−0.231	**−0.111**
Sanandaj	−0.617[b]	−0.548[b]	**0.256**
Shiraz	−0.184	−0.066	0.047
Tabriz	−0.494[b]	−0.451[b]	**0.067**
Tehran	−0.216	−0.197	**0.025**
Zabol	−0.256	−0.335[a]	0.719[b]
Zanjan	−0.331[a]	−0.447[b]	**0.224**

Note: To assess trend of changes, in normal data series Pearson test and in non-normal data series that showed with bold characters Spearman Rho test were used.
[a] Trend of changes is significant at the 0.05 levels.
[b] Trend of changes is significant at the 0.01 levels.

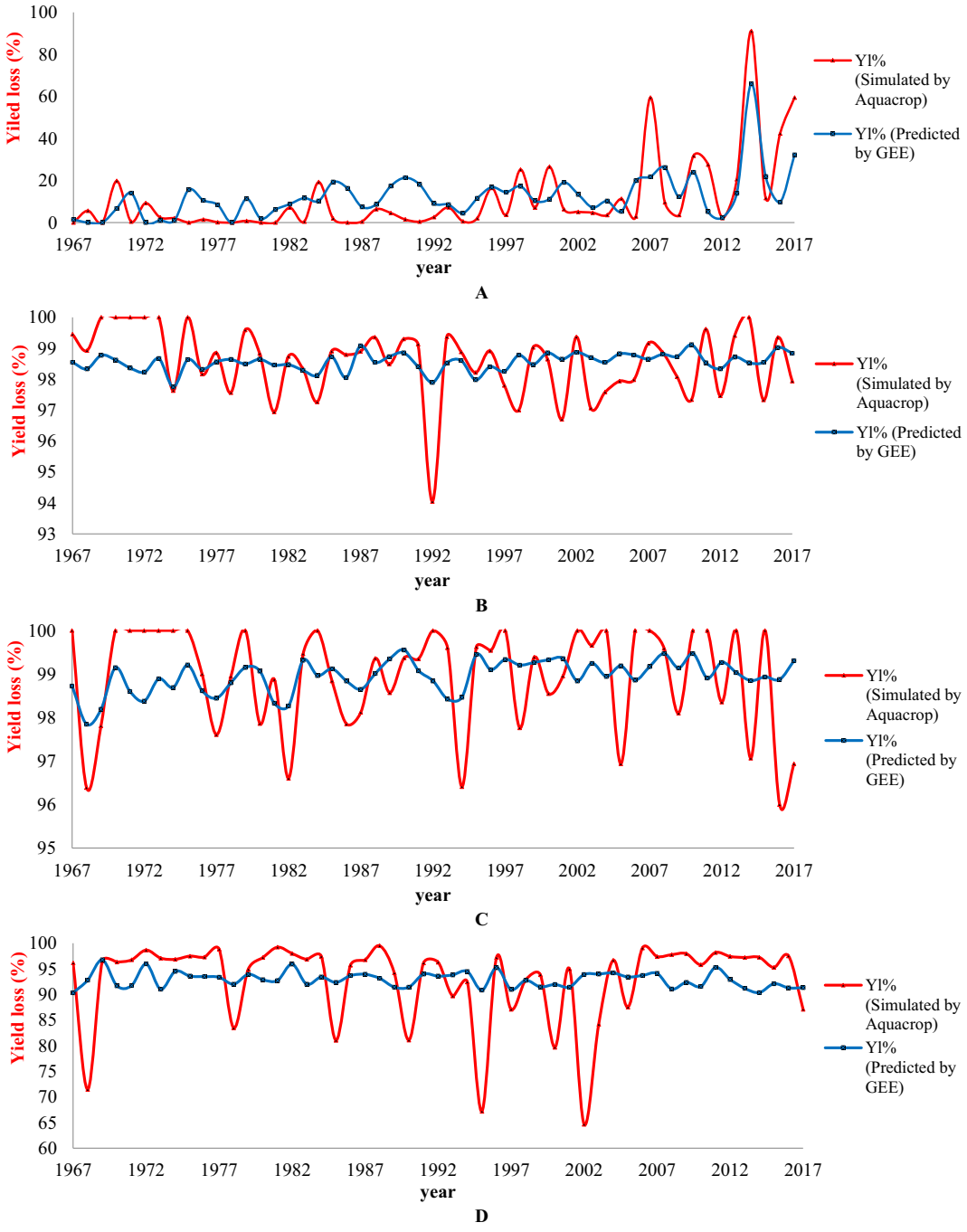

Fig. 6. Simulated AYL (%) using AquaCrop model and predicted AYL (%) using simple GEE method (using only data series of De-Martonne index) in some of the selected stations (for example). A: Gorgan Station, B: Kerman Station, C: Tabriz Station and D: Tehran Station.

Kerman, Tehran stations were arid, the climate condition of Arak, Ghazvin, Mashhad, Sanandaj, Shiraz, Tabriz and Zanjan stations were semi-arid, the climate condition of Gorgan station was the Mediterranean, the climate condition of Babolsar station was humid and the climate condition of Ramsar and Rasht stations were hyper humid type A. According to the results of MDM index in short-term, in stations with hyper-arid to semi-arid climate conditions occurrence frequency of arid and semi-arid classes and in stations with Mediterranean to hyper humid type A climate conditions occurrence frequency of humid and sub-humid classes of climate condition were more than other classes (Fig. 4 and Table 4).

3.3. Calculated annual yield loss (%) of rain-fed winter wheat

Calculated AYL in rain-fed winter wheat using AquaCrop model in all stations indicated that the level of AYL in stations with hyper- arid, arid and semi-arid climate conditions such as Zabol, Tehran, Esfahan and Arak stations were more than stations with hyper- humid and humid climate conditions such as Ramsar, Rasht and Babolsar. Results showed, the AYL in Ahvaz, Arak, Babolsar, Esfahan, Ghazvin, Gorgan, Kerman, Mashhad, Ramsar, Rasht, Sanandaj, Shiraz, Tabriz, Tehran, Zabol and Zanjan stations varies from 13.67% to 100%, 57.48% to 100%, 0.00% to 23.76%, 95.03% to 100%, 48.96% to 100%, 0.00% to 91.15%, 94.05% to

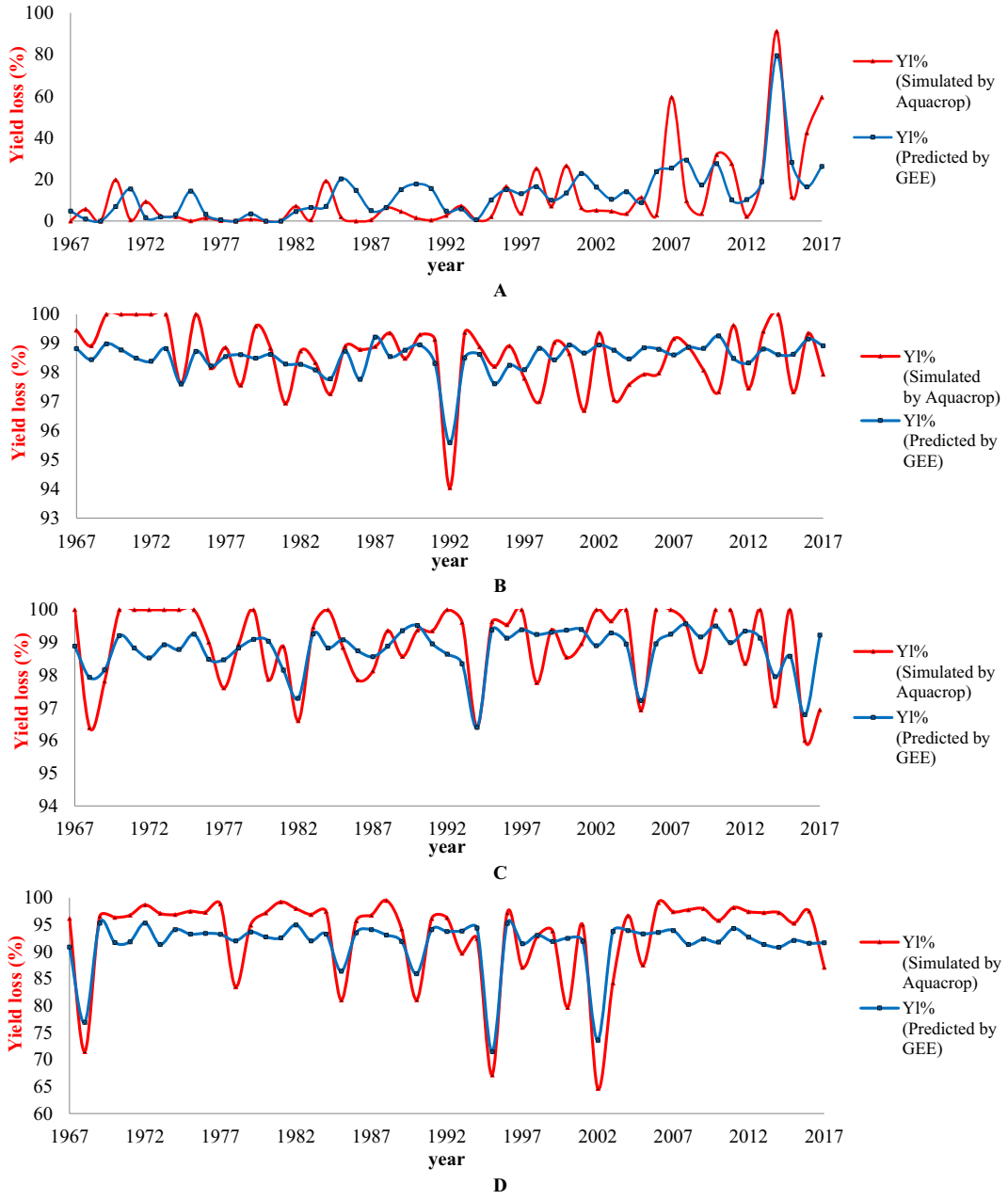

Fig. 7. Simulated AYL (%) using AquaCrop model and predicted AYL (%) using GEE method (using only data series of UNEP Aridity Index) in some of the selected stations (for example). A: Gorgan Station, B: Kerman Station, C: Tabriz Station and D: Tehran Station.

100%, 21.34% to 98.75%, 0.00% to 32.11%, 0.00% to 42.42%, 24.88% to 99.13%, 27.00% to 99.50%, 96% to 100%, 64.65% to 99.50%, 91.44% to 100% and 86.63% to 100%, respectively (Fig. 5 for example).

3.4. Trend assessment of calculated climate indices and calculated AYL

Normality test of calculated data series of UNEP, MDM and AYL indicated that data series of UNEP and MDM indices in all stations were normal at 5% significant level. According to the results, data series of AYL in Ahvaz, Babolsar, Esfahan, Kerman, Shiraz and Zabol stations were normal at 5% significant level and in other stations were non-normal (Table 5). So, to assess the trend of changes in data series of UNEP and MDM indices in all stations and data series of AYL in Ahvaz, Babolsar, Esfahan, Kerman, Shiraz and Zabol stations, Pearson test was used (for data series of AYL in other stations Spearman Rho test were used). Results indicated, the trend of changes in calculated climates indices based on MDM method in 93.75% of stations were decreasing (drying). Decreasing trend of climate conditions in Ahvaz, Arak, Gorgan, Kerman, Mashhad, Rasht, Sanandaj, Tabriz and Zanjan stations were significant at 5% or 1% levels. The trend of changes in calculated UNEP aridity index in 87. 5% of stations were decreasing (drying). Decreasing trend of climate conditions in Ahvaz, Arak, Gorgan, Mashhad, Sanandaj, Tabriz, Zabol and Zanjan stations were significant at 5% or 1% levels. Trend assessment showed, changes trend in data series of simulated AYL (%) using AquaCrop model in 81.25% were increasing (Percentage of yield reduction were increasing). Increasing trend of AYL in Arak, Esfahan, Gorgan and Zabol stations were significant at 5% or 1% levels (Table 6).

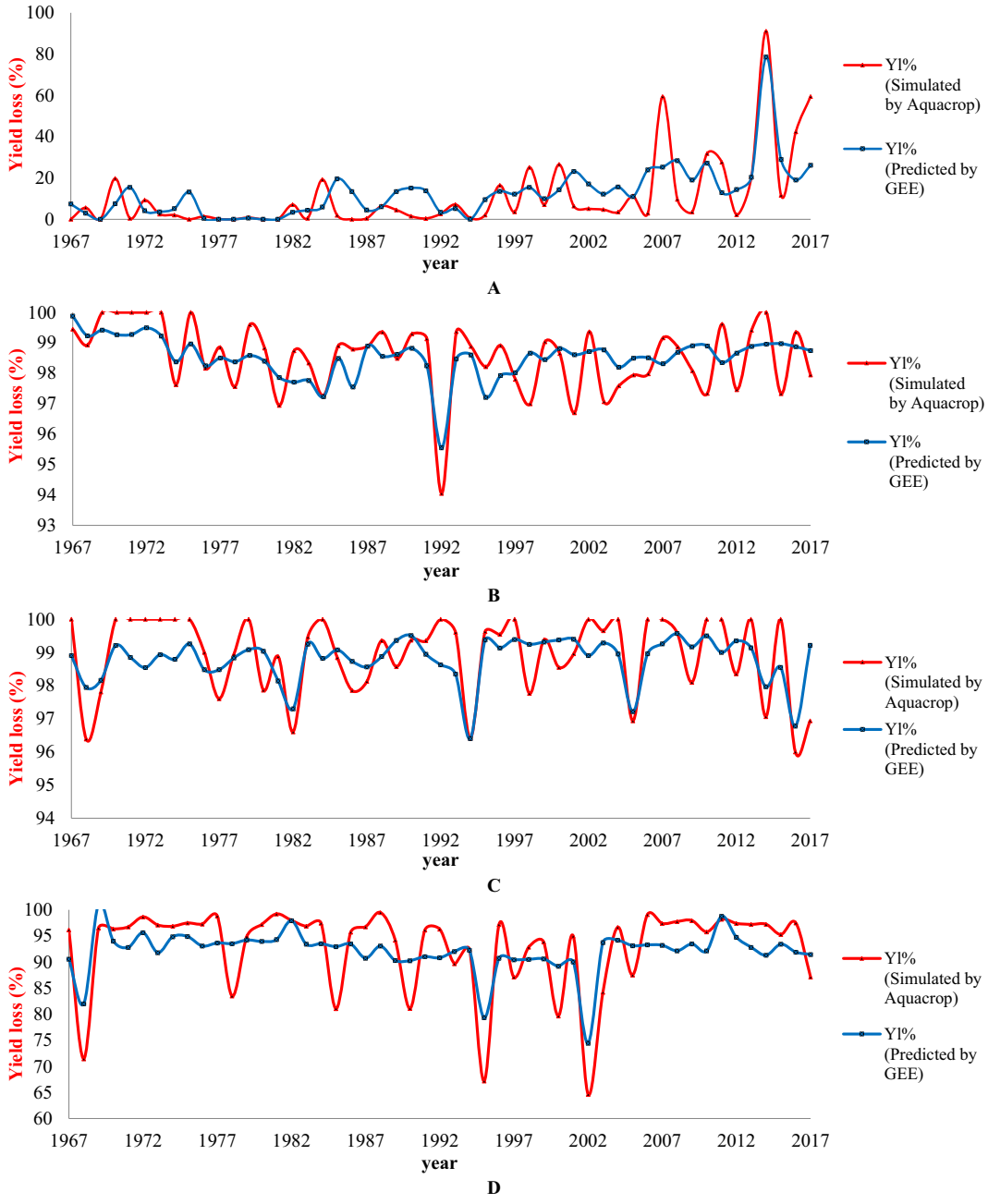

Fig. 8. Simulated AYL (%) using AquaCrop model and predicted AYL (%) using multiple GEE method (using data series of De-Martonne index and UNEP Aridity Index together) in some of the selected stations (for example). A: Gorgan Station, B: Kerman Station, C: Tabriz Station and D: Tehran Station.

3.5. Comparison of the accuracy of UNEP and MDM indices to monitor climate conditions

In this paper for monitoring the accuracy of UNEP and MDM indices to monitor climate conditions, in the first stage, |*B*| coefficient values of simple GEE between simulated AYL (%) using AquaCrop model and MDM indices and simple GEE between simulated AYL (%) using AquaCrop model and UNEP indices, |*B*| coefficient values of multiple GEE between simulated AYL (%) using AquaCrop model and MDM indices and UNEP indices (together) and R^2 coefficients between predicted AYL (%) using simple and multiple GEE methods (Figs. 6, 7 and 8) and simulated AYL (%) using AquaCrop model at all station were used. Results of |*B*| coefficient values of simple and multiple GEE indicated that, |*B*| coefficient values of simple GEE based on simulated AYL (%) using AquaCrop model and UNEP index at all stations were more than |*B*| coefficient values of simple GEE based on simulated AYL (%) using AquaCrop model and MDM index, on the other hand, |*B*| coefficient values of UNEP parameters in multiple GEE were more than MDM parameters (Tables 7 and 8). Therefore, obtained results showed that the impact of data series of UNEP aridity index at the all stations were more than MDM data series (This impact at stations with hyper-arid, arid and semi-arid climate conditions were more than stations with hyper-humid and humid climate conditions). According to the results of R^2 coefficients between predicted AYL (%) using simple and multiple GEE methods and simulated AYL (%) using AquaCrop model, at the all stations with different climate conditions, R^2 coefficients between predicted AYL (%) using simple and multiple GEE methods in Esfahan, Kerman, Tabriz, Tehran, Zabol and Zanjan stations were similar and equal to 1, 1, 1, 0.993, 1, 0.999, respectively. In Ahvaz, Arak, Babolsar, Ghazvin, Ramsar, Sanandaj and Shiraz stations R^2 coefficients between predicted

Table 7
|*B*| coefficients between calculated annual yield loss (%) and Modified De-Martonne index using Simple GEE method and |*B*| coefficients between calculated annual yield loss (%) and UNEP Aridity index using Simple GEE method.

Stations name	B coefficient	
	B_d	B_u
Ahvaz	4.793	327.695
Arak	0.113	1.595
Babolsar	0.065	2.734
Esfahan	0.032	2.814
Ghazvin	0.289	4.698
Gorgan	1.668	58.660
Kerman	0.149	14.425
Mashhad	1.358	83.336
Ramsar	0.071	1.888
Rasht	0.021	0.162
Sanandaj	0.957	67.125
Shiraz	0.961	81.285
Tabriz	0.109	7.934
Tehran	0.561	26.948
Zabol	0.851	93.921
Zanjan	0.082	11.358

Note. B_d is |*B*| coefficients between calculated annual yield loss (%) and Modified De-Martonne index using Simple GEE method and B_u is |*B*| coefficients between calculated annual yield loss (%) and UNEP Aridity index using Simple GEE method.

AYL (%) using simple GEE method (based on UNEP aridity index data series) and simulated AYL (%) using AquaCrop model were the highest values and R^2 coefficients between predicted AYL (%) using simple GEE method (based on MDM index data series) and simulated AYL (%) using AquaCrop model were the lowest values. In Gorgan, Mashhad and Rasht stations R^2 coefficients between predicted AYL (%) using multiple GEE method and simulated AYL (%) using AquaCrop model were the highest values and R^2 coefficients between predicted AYL (%) using simple GEE method (based on MDM index data series) and simulated AYL (%) using AquaCrop model were the lowest values (Table 9).

4. Conclusion

Climate changes in globally level affected by human activities and increasing of greenhouse gases have caused the various problems such as global warming, negative impacts in sustainable development and etc. In recent decades, the issue of climate changes and its importance at the global level is taken into consideration. Holding international conferences and international protocols such as Kyoto Protocol (1992), Paris Climate Agreement (2015) and etc., are reasons for this claim.

Table 8
|*B*| coefficients between calculated Modified De-Martonne index and UNEP Aridity index (**together**) and annual yield loss (%) using multiple GEE method.

Stations name	B coefficient	
	B_d	B_u
Ahvaz	4.151	563.606
Arak	1.488	78.567
Babolsar	0.221	9.482
Esfahan	0.512	32.584
Ghazvin	2.804	138.259
Gorgan	0.842	80.418
Kerman	0.799	68.261
Mashhad	7.503	423.187
Ramsar	0.129	1.833
Rasht	0.346	10.585
Sanandaj	2.647	204.615
Shiraz	7.718	546.190
Tabriz	0.010	8.618
Tehran	4.001	213.524
Zabol	5.510	584.630
Zanjan	1.029	65.637

Note. B_d is |*B*| coefficients of Modified De-Martonne index and B_u is |*B*| coefficients of UNEP Aridity index.

Table 9
R^2 coefficients between simulated annual yield loss (%) using AquaCrop model and predicted annual yield loss (%) using simple and multiple GEE methods.

Stations name	R^2 coefficient		
	R_d^2	R_u^2	R_{ud}^2
Ahvaz	0.898	0.908	0.907
Arak	0.992	0.997	0.992
Babolsar	0.456	0.467	0.460
Esfahan	1.000	1.000	1.000
Ghazvin	0.987	0.989	0.988
Gorgan	0.417	0.488	0.490
Kerman	1.000	1.000	1.000
Mashhad	0.970	0.972	0.976
Ramsar	0.190	0.192	0.191
Rasht	0.202	0.202	0.217
Sanandaj	0.965	0.972	0.971
Shiraz	0.938	0.948	0.946
Tabriz	1.000	1.000	1.000
Tehran	0.993	0.993	0.993
Zabol	1.000	1.000	1.000
Zanjan	0.999	0.999	0.999

Note. R_d^2 is R^2 coefficients between predicted annual yield loss (%) using Simple GEE method (based on Modified De-Martonne index data series) and simulated annual yield loss (%) using AquaCrop model. R_u^2 is R^2 coefficients between predicted annual yield loss (%) using Simple GEE method (based on UNEP Aridity index data series) and simulated annual yield loss (%) using AquaCrop model and R_{ud}^2 is R^2 coefficients between predicted annual yield loss (%) using Multiple GEE method (based on Modified De-Martonne index and UNEP Aridity index data series together) and simulated annual yield loss (%) using AquaCrop model.

So, monitoring the climatic conditions in different parts of the world is very important to reduce the negative impacts of this phenomena. In this study, at the first stage, the changes trend in climate conditions in Iran were evaluated using UNEP aridity index and Modified De-Martonne index from 1967 to 2017. Then, the accuracy of UNEP and MDM indices to assess climate conditions based on relationship between changes in mentioned climate indices and changes in annual yield loss (%) of rain-fed winter wheat using simple and multiple GEE were compared. Results of this paper showed that, based on UNEP and MDM indices, climate indices in 93.75% and 87.5% of stations had a decreasing trend (respectively). This finding shows that Iran's climate is drying. The results of this paper are similar to the results of Nouri and Bannayan (2018) research that showed a downward trend in precipitation and aridity index in Iran over 1966 to 2012. It seems, decreasing trend of climate conditions in Iran (Iran is drying) returns to decreasing trend in precipitation and increasing trend in average temperature and average evapotranspiration in Iran in recent years. On the other hand, according to the results, at the all stations correlation between predicted AYL (%) of rain-fed winter wheat using GEE model based on UNEP aridity index and simulated AYL (%) using AquaCrop model were more than the correlation between predicted AYL (%) using GEE model based on MDM index and simulated AYL (%) using AquaCrop model. Results indicated, the accuracy of the UNEP aridity index to assess climate conditions were more than MDM index. This result can be due to the number of climatic parameters that have been used to calculate the UNEP aridity index (UNEP aridity index is based on precipitation and PET parameters that to calculate PET, many different climatic parameters are used but MDM index is only bade on precipitation and temperature parameters). Therefore, it is recommended to use UNEP aridity index to assess climate conditions in different regions.

Conflict of interest

The authors declare that they have no conflict of interest.

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